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The width difference of B_s-mesons

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Outline

1. Heavy Quark Expansion
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1. Heavy Quark Expansion

Voloshin, Shifman; Bigi, Uraltsev, Vainshtein

Optical theorem for total decay rate Γ:

$$\Gamma \quad \propto \quad \text{Im}\, \langle B|\, i \int d^4x\, T\, \mathcal{H}_{eff}(x)\mathcal{H}_{eff}(0)|B\rangle$$

$\mathcal{H}_{eff}$ is the effective $|\Delta B| = 1$ hamiltonian.
HQE $=$ Operator product expansion:

$$\Gamma \quad \propto \quad G_F^2 \sum_j m_b^{8-d_j}\, c_j\, (\mu/m_b)\, \underbrace{\langle B|\mathcal{O}_j\,(\mu)\,|B\rangle}_{\mathcal{O}\left(\Lambda_{QCD}^{d_j-3}\right)}$$

- c_j: Wilson coefficients containing physics from scales $\geq \mu = \mathcal{O}(m_b)$
- $\mathcal{O}_j$: local operators with dimension $d_j \geq 3$.

Effect: Expansion of Γ in Λ_{QCD}/m_b and $\alpha_s(m_b)$.

$$\Gamma\left(\mathrm{B}\to all\right) = \Gamma\left(\mathrm{b}\to all\right) + \mathcal{O}\left(\frac{\Lambda_{QCD}^2}{m_b^2}\right)$$

First term: QCD corrected parton model.

First corrections are $\mathcal{O}\left(\frac{\Lambda_{QCD}^2}{m_b^2}\right)$ and come from Fermi motion of the b-quark and the chromomagnetic interaction with the light degrees of freedom.

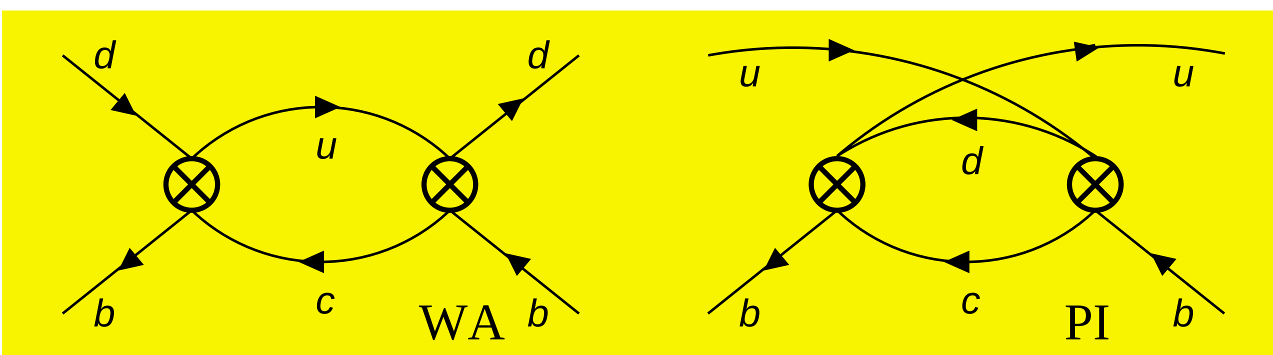
Validity of HQE $\Leftrightarrow$ Quark-hadron duality

2. Lifetime differences

Dominant source of lifetime differences between B_d, B_s and $B^{\pm}$ mesons: Participation of the spectator quark in the weak decay. Effect of order $\mathcal{O}\left(16\pi^2 \frac{\Lambda_{QCD}^3}{m_b^3}\right)$

(Exception: $\tau(B_s) - \tau(B_d)$ stems from $SU(3)_F$ breaking in $\mathcal{O}\left(\frac{\Lambda_{QCD}^2}{m_b^2}\right)$ matrix elements.)

B_d–$B^{\pm}$ lifetime difference:



Bigi, Shifman, Uraltsev, Vainshtein
Neubert, Sachrajda

Lifetime difference of B_s mesons:

$$\mathrm{B_s} \sim \bar{b}s \qquad \overline{\mathrm{B}}_\mathrm{s} \sim b\bar{s}$$

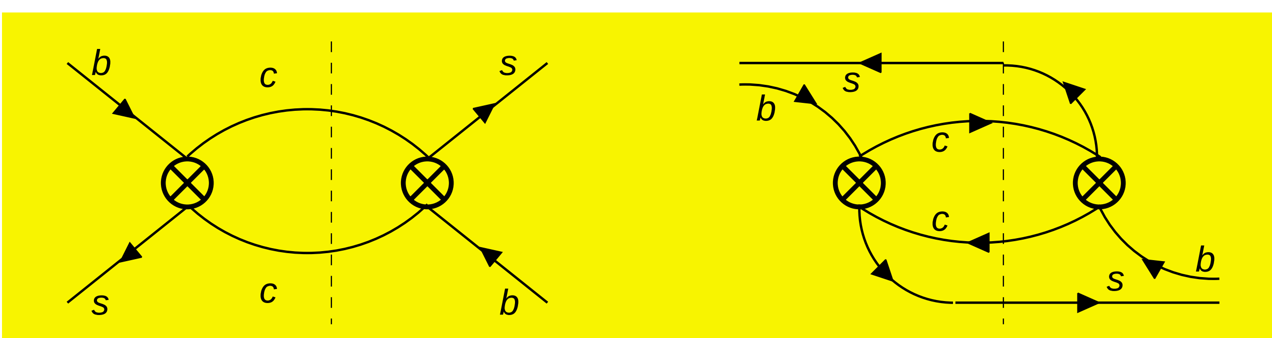
Standard Model: Negligible CP-violation in $\mathrm{B_s}$–$\overline{\mathrm{B}}_\mathrm{s}$–mixing:

$$|\, B_{L,H} \,\rangle = \frac{1}{\sqrt{2}} \left[|\, B_s \,\rangle \mp |\, \overline{B}_s \,\rangle \right]$$

Width difference

$$\Delta\Gamma_{B_s} \equiv \Gamma_L - \Gamma_H$$
$$= -\frac{1}{M_{B_s}} \,\mathrm{Im}\, \langle \bar{B}_s |\, i \int d^4x \; T\, \mathcal{H}_{eff}(x) \mathcal{H}_{eff}(0) | B_s \rangle$$

from final states common to $\mathrm{B_s}$ and $\overline{\mathrm{B}}_\mathrm{s}$



Measurement at Tevatron Run-II: Compare average B_s lifetime $\tau(B_s)$ measured in $B_s \to D_s^- \pi^+$ with $\tau(B_{s,L}) = 1/\Gamma_L$ measured in $B_s \to \psi\phi$ (CP-even component).

Compare:

$\tau(B^+)/\tau(B_d)$:
insensitive to new physics $\Rightarrow$ tests HQE

$\tau(B_s)/\tau(B_d) \simeq 1 \pm \mathcal{O}(1\%)$ (in Standard Model):
mildly sensitive to new physics in penguin coefficients

Keum, U.N.

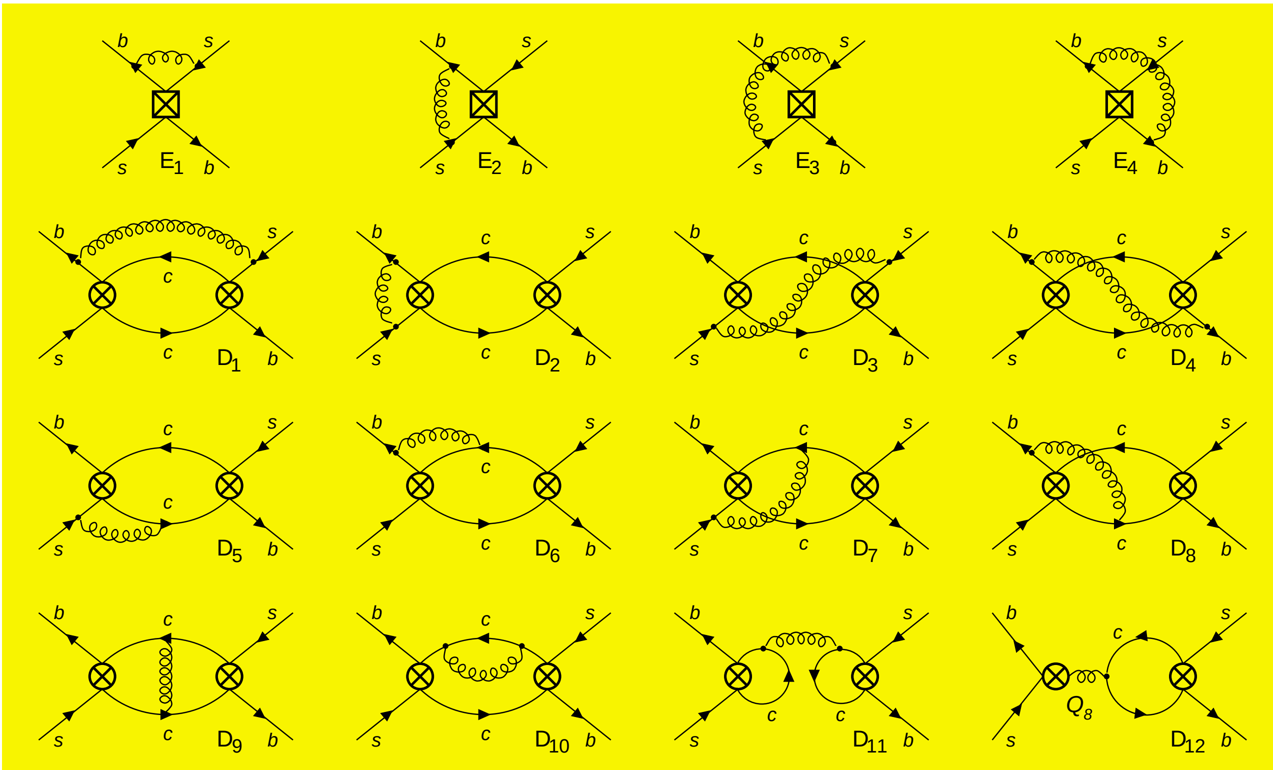
$\tau(B_{s,L})/\tau(B_{s,H})$:
New CP-violating physics in B_S–$\overline{B}_S$–mixing can suppress $\Delta\Gamma_{B_s}$ below its SM value.

Grossman

Why calculate lifetime differences to $\mathcal{O}(\alpha_s)$?

- to reduce the sizable μ-dependence
- consistent use of $\Lambda_{\overline{MS}}$
- meaningful use of lattice results
  for hadronic matrix elements like $\langle \bar{B}_s|\mathcal{O}|B_s\rangle$, $\langle \bar{B}_s|\mathcal{O}_S|B_s\rangle$
- QCD corrections are of order 30%.
- verify infrared safety of the c_j's.
- Test of quark-hadron duality:
  Need to go beyond leading logarithmic approximation.

3. The width difference of B_S–mesons



Result:

$$\text{Im}\, \langle \bar{B}_s |\, i \int d^4x\, T\, \mathcal{H}_{eff}(x) \mathcal{H}_{eff}(0) | B_s \rangle$$

$$= -\frac{G_F^2 m_b^2}{12\pi} \left(V_{cb}^* V_{cs} \right)^2 \, \left[F(z) \langle \bar{B}_s | Q | B_s \rangle + F_S(z) \langle \bar{B}_s | Q_S | B_s \rangle \right]$$

F and F_S are IR-safe functions of $z = m_c^2 / m_b^2$.

IR-singularities cancel via two mechanisms:

1. Bloch-Nordsiek cancellations among different cuts of the same diagram
2. factorization of IR-singularities, which end up in $\langle \bar{B}_s | \mathcal{O} | B_s \rangle$, $\langle \bar{B}_s | \mathcal{O}_S | B_s \rangle$

Nonperturbative QCD in

$$\langle \bar{B}_s | Q | B_s \rangle = \frac{8}{3} f_{B_s}^2 M_{B_s}^2 B$$
$$\langle \bar{B}_s | Q_S | B_s \rangle = -\frac{5}{3} f_{B_s}^2 M_{B_s}^2 \frac{M_{B_s}^2}{(\bar{m}_b + \bar{m}_s)^2} B_S$$

Include corrections of order Λ_{QCD}/m_b:

Beneke, Buchalla, Dunietz 1996

$$\left(\frac{\Delta\Gamma}{\Gamma}\right)_{B_s} = \left(\frac{f_{B_s}}{245 \text{ MeV}}\right)^2 [0.008\, B + 0.204\, B_S - 0.086]$$

for the $\overline{\text{MS}}$-scheme at $\mu = m_b$.

Quenched lattice QCD:

$$B(\mu = m_b) = 0.80 \pm 0.15$$ Hashimoto (Lattice '99)

$$B_S(\mu = m_b) = 1.19 \pm 0.20$$ Yamada et al. (Hiroshima)

$$\left(\frac{\Delta\Gamma}{\Gamma}\right)_{B_s} = \left(\frac{f_{B_s}}{245 \text{ MeV}}\right)^2 (0.162 \pm 0.041 \pm ??? \text{ (latt. syst.)})$$

Summary

1. Need $\mathcal{O}(\alpha_s)$ corrections to test the HQE predictions for the lifetime differences of B mesons.

2. New CP-violation in B_s-mixing affects $\Delta\Gamma_{B_s}$.

3. Next-to-leading QCD-corrections to $\Delta\Gamma_{B_s}$ are infrared safe and reduce $\Delta\Gamma_{B_s}$ by 30%.
   $\Delta\Gamma_{B_s}/\Gamma_{B_s} = (16 \pm 7)\%$.